Water Use Measurements of the Bio-diesel Tree *Jatropha curcas*: Initial Results

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ABSTRACT

High oil prices, linked to increasing demand, tougher environmental requirements, and burgeoning extraction costs and risks are some of the pressures that are influencing the quest for alternative, cleaner and economically viable forms of energy. One response to these trends is the proposed introduction of bio-energy species for large-scale planting and bio-fuel production in South Africa. However, questions around the potential hydrological and ecological effects of the associated land use changes remain unanswered due to a lack of information. Confident quantification of the impacts of these species on water resources are matters that are currently open to debate, because of insufficient field-based experimental or other direct research under South African conditions. A project was initiated to investigate the potential hydrological impacts associated with the wide-scale planting of one such bio-diesel producing tree, namely *Jatropha curcas*. Process studies of *J. curcas* water use were initiated at selected sites in KwaZulu-Natal, using appropriate techniques (site water balance and evapotranspiration measurements). This paper reports on the initial, mid-project findings of the study.

Keywords: *Jatropha curcas, water use, bio-diesel, heat pulse velocity*

1 INTRODUCTION

The South African interest in *Jatropha curcas* has been highlighted in recent years by renewed interest in business opportunities promoting alternative energy sources and poverty alleviation efforts. A number of private business proposals, from national and international investors, to establish the species as a bio-energy / bio-diesel initiative have been actively pursued. The prime ingredient in the manufacture of bio-diesel is vegetable oil (e.g. sunflower, soya and peanut oil), however, these oils are edible and generally fetch higher prices as food-stuffs, which precludes them from being used in bio-diesel production. Research by the various interested businesses indicated that *J. curcas*, whose oil is inedible (toxic) to humans and animals, merited serious consideration as a viable alternative. Other than extracting bio-diesel from *J. curcas* seeds, the leaves, roots and bark may also potentially be used for numerous other industrial and pharmaceutical uses. However, questions around the potential environmental impacts (e.g. invasiveness and water use) of this species are currently open to debate, because of insufficient research under South African conditions. The growing interest in this species has now reached a stage where the relevant government departments (Water Affairs and Forestry, Agriculture, Environmental Affairs, Minerals and Energy etc.) require the information necessary to make an informed decision on whether or not to allow the wide scale propagation and commercialisation of this crop. In order to manage it is necessary to measure. The effective management of *J. curcas* in terms of water resources will require accurate data on generalised water use patterns, relevant to areas having planting potential. These sorts of uncertainties require clarification through a combination of process-based field measurements and modelling exercises.

2 *JATROPHA CURCAS*

J. curcas belongs to the very large Euphorbiaceae family. It has numerous common names assigned to it by different languages or countries, but is most commonly referred to as the physic nut, Barbados nut or purging nut. In South Africa the Zulu common name is the Maluku. It is a multi-purpose tree of Mexican and Central American origin with a long history of cultivation in tropical America, Africa and Asia. Considerable amounts of physic nut seed were produced on the islands of Cape Verde during the first half of the twentieth century, constituting an important contribution to the country's economy. Seeds were exported to Lisbon and Marseille for oil extraction and soap production (Becker and Makkar, 2000).

The form of *J. curcas* is a shrub or tree with smooth grey bark, spreading branches and stubby twigs, which exude a milky or yellowish sap when broken. Estimates of maximum height vary from 5 to 8 m in height, and are probably dependant on growing conditions. Its leaves are deciduous, 3 to 5-lobed in outline, 6–40 cm long and 6–35 cm broad. Its yellowish flowers are bell-shaped. Pollination is by insects, usually bees. Fruits are produced which are 2.5–4 cm long, finally drying and splitting into 3 valves, all or two of which commonly have an oblong black seed (Morton, 1977; Little et al., 1974). Under good rainfall conditions, seed production begins within 12-18 months but reaches maximum productivity after 4 to 5 years. The oil content of the seeds is approximately 35% (Henning, 1996). Although trials with non-toxic varieties have been reported (Gubitz, 1997), the seeds of *J. curcas* are commonly reported to be toxic to humans and animals (Duke, 1983; Begg and Gaskin, 1994).

Animals do not usually eat the tree, and the plants are consequently frequently grown as natural hedges. However, Begg and Gaskin (1994) caution that they will consequently often be found in gardens and public areas and will therefore be easily accessible, especially to children. Two publications document the poisoning of South African children by *J. curcas* (Joubert *et al*., 1984; Mampane *et al*., 1987).

The tree is fast growing, multipurpose and drought resistant, and can be cultivated in areas of low rainfall, although yield (seed production) is linked to growing conditions. The trees require a minimum Mean Annual Precipitation (MAP) of 250mm; they grow comfortably with 500mm or more, but grow optimally with an annual precipitation of up to 1200mm (Becker and Makkar, 2000). Where annual rainfall is high (>1000 mm), it does better in hot rather than temperate climates. In dry seasons it tends to shed its leaves. It can grow in soils that are quite infertile, and is usually found at lower elevations (below 500 m.). *J. curcas* grows best on well-drained soils with good aeration, but adapts well to marginal soils with low nutrient content (PIER, 2004). The trees prefer a slight to medium slope of ground as opposed to flat ground, but do not tolerate waterlogged soils (JANUS, 2004). Since it will survive with little or no fertilizer input, it is an attractive species for resource-poor farmers, although higher rainfall and fertilizer inputs can substantially increase its yields (Pratt *et al.*, 2002). *J. curcas* is considered to be a multi-purpose tree with potential products from, and uses of, the leaves, bark, seeds (oil) and roots.

3 METHODS AND MATERIALS

A process-based research and modelling study was initiated with the objective of developing predictive capability on the impacts of large-scale planting of *Jatropha curcas* on water resources in South Africa. The project is funded by the Water Research Commission (WRC) and endorsed by the Department of Water Affairs and Forestry (DWAF). The project team comprises a consortium of private consultancies (Siyaphambili Development Consulting, CPH Water, MSSA, Dirk Versfeld c.c.) and a science council (CSIR). The full project includes; 1) hydrological process studies and modelling, 2) assessment of the biophysical requirements of *J. curcas* through an ARC-View GIS modelling exercise, 3) gauging the perceptions and levels of understanding of Streamflow Reduction Activity (SFRA) processes and licensing amongst users of *J. curcas* through field surveys, and 4) the provision of recommendations to the WRC and DWAF (SFRA licensing committee) regarding SFRA declaration and regulation. However, for the purposes of this paper only the hydrological process studies of *J. curcas,* as being undertaken by the CSIR, are reported on.

3.1 Site Selection

J. curcas is likely to produce higher yields under sub-tropical conditions, which makes it suitable for cultivation along the KwaZulu-Natal (KZN) coastal belt of South Africa. Consequently, monitoring sites were sought in the Zululand region of the KZN North Coast, and the following two sites were selected:

1. 3-year-old trees at the Owen Sithole College of Agriculture near Empangeni, and
2. 11-year-old trees along a fenceline at a homestead in the Makhathini flats, north of Jozini.

The Owen Sithole College of Agriculture (OSCA) is located approximately 20 km’s outside Empangeni, on the KZN north coast. The first site selected for monitoring (Grid reference S 28º 38’ 36.7”; E 31º 55’ 36” and Altitude 44.2 masl) consists of a *J. curcas* trial at OSCA that was planted in January 2002. It is a valley-bottom site, close to a stream but non-riparian, being approximately 30m from the stream channel. The site is maintained under controlled conditions (weed control, but no irrigation), and there are 24 trees in the trial planted in two blocks of 6X2 trees. Spacing is 4.5m (between rows) by 3.0m (within rows). The 3-year old trees were 2.5m tall, had stem diameters of approximately 10cm at a stem height of 15cm, and a bark thickness of 7mm when monitoring commenced on 27 January 2005.

The second site selected for monitoring consists of mature *J. curcas* trees situated along the fence-line of a rural homestead in the Makhathini flats region of Northern Zululand (Grid reference S 27º 24’ 06.9”; E 32º 11’ 48.6” and Altitude 75.2 masl). The site is non-riparian and lies approximately 20 km’s east of Jozini close to the Makhathini Research Station. The trees were estimated to be approximately 11-years old (planted January 1994) when monitoring commenced on 4 March 2005.

3.2 Instrumentation

Continuous measurements of evapotranspiration (using the Heat Pulse Velocity technique), climatic variables (using a fully automatic weather station) and soil water dynamics (using Watermark sensors for matric potential and CS616 probes for water content) are being carried out at the OSCA site. Only sap flow measurements and temperature / relative humidity measurements are being conducted at the Makhathini site. Basic descriptions of the instrumentation and monitoring techniques are given below.

3.2.1 Heat Pulse Velocity Technique

The heat pulse velocity (HPV) technique is an appropriate technique for measurement of sap flow rates in trees. The heat ratio method (HRM) of operation applied in the HPV technique is fully described in Burgess *et al.*, 2001, however the description below is given for the readers benefit, and is drawn largely from that reference.

The heat ratio method measures the ratio of the increase in temperature, following the release of a pulse of heat, at points equidistant below and above a heater probe. In order to achieve this, three parallel holes are accurately drilled (with the help of a drill guide strapped to the tree) into the sapwood (xylem) portion of tree trunks. The upper and lower holes are both situated 5mm from the central hole (above and below, respectively).

Copper-constantan thermocouples, wired to a multiplexer or logger, are inserted into the upper and lower holes to a specific depth below the cambium (below-bark insertion depth). A heater probe, wired to a relay control module, is inserted into the central hole.

At a pre-determined time interval (usually hourly), the temperatures in the upper and lower thermocouples are measured and the ratio (upper over lower) is logged. Directly thereafter, the central (heater) probe releases a short (0.5 second) pulse of heat, which diffuses through the adjacent wood and is taken up by the sap moving upwards through the xylem of the tree. As the heat pulse is carried up the tree by the sap, the upper thermocouple begins to warm. Logging of the changing heat ratio commences 60 seconds after the initiation of the heat pulse and is measured continuously (approximately every second, depending on the processing speed of the logger) until 100 seconds after the heat pulse. The average of these ratios is calculated and utilised in subsequent formulae to derive the sap velocity. These formulae are described in Burgess *et al.*, 2001. Further measurements of sapwood area, moisture content and density, as well as the width of wounded (non-functional) xylem around the thermocouples, are used to convert sap velocity to a total sap flow rate for the entire sample tree. These measurements are usually taken at the termination of the experiment due to the destructive sampling required to obtain them. The conversion of sap velocity to sap flow is readily derived as the product of sap velocity and cross-sectional area of conducting sapwood. Gross wood cross-sectional area is calculated from its under-bark radius. Heartwood is discounted by staining the sapwood or by observing the dark colour often associated with heartwood. Where sap velocity is estimated at several radial depths, total sapwood area is divided into concentric annuli delimited by midpoints between measurement depths. In this way, point estimates of sap velocity are weighted according to the amount of conducting sapwood in the annulus they represent (Burgess *et al.*, 2001).

The number of probe sets (2 thermocouples and one heater) utilised per tree is determined arbitrarily by the diameter of the tree, but typically range from 4 to 12. The thermocouples are inserted to four different depths, since flow rates are fastest in the younger xylem near the cambium and slower in the older, deeper xylem. The thermocouple insertion depths used for the OSCA trees (including bark) were 14, 21, 28 and 35mm below the surface, while those for the Makhathini trees were 14, 21, 30 and 40mm. Data loggers were programmed to initiate the heat pulses and record the heat ratio changes in the respective thermocouple sensor pairs. Cellular phone modems connected to the loggers allow remote downloading of data as well as uploading of revised programmes to the logger. In order to minimise battery usage by the modem it is programmed to only switch on for a couple of hours each day during which time remote data transfer operations can be carried out.

3.2.2 Soil Sensors

Soil water retention is an important parameter that regulates the storage and movement of water within the soil and ultimately plant growth. Whereas water content provides an indicator of the actual volume of water stored in the soil, water potential provides a measure of the tension or matric potential, which relates the pressure with which water is held in the soil against atmospheric pressure. To prove or disprove the hypothesis that *J. curcas* trees cause significant changes in soil water dynamics, continuous measurements of soil water content (infiltration and abstraction) are being carried out at two locations at the OSCA site. These consist of a tree site (with the sensors directly beneath the tree, in and below the root zone) and a control, grassland site (with the sensors at corresponding depths beneath the soil surface) for comparative purposes. The grass site consists of mown Kikuyu. Appropriate instrumentation, namely Watermark sensors for matric potential and CS616 probes for water content measurements, are being utilised. The Watermark sensors were installed to depths of 15, 40, 80 and 120cm below soil surface, while the CS616 probe insertion depths were 15, 40 and 120cm below soil surface. To ensure a proper seal between the sensors and the soil a weak slurry, containing the recently excavated soil, was poured down the access shaft before inserting the sensors.

A complete analysis of soil physical properties at the site is planned. This will include double-ring infiltrometer tests and the collection of undisturbed cores as part of a full water retention study for the site.

3.2.3 Automatic Weather Station

A complete automatic weather station is used to monitor rainfall, solar radiation, air temperature, relative humidity, wind speed and wind direction at the OSCA site. Climatic conditions are continuously measured at 10 s intervals, and averaged or totalled at hourly intervals. Initially, a solar panel was used to charge the battery that powers the system, however after the loss of the solar panel due to theft the battery alone was utilised. It provides sufficient power to run the system continually for approximately three months, after which the battery is swapped out with a fully charged unit.

The above process-based measurements will ensure that a complete water balance is established for the site(s). They will also ensure that the variables required by the chosen models are available in order to calibrate the model for the monitoring site(s) before extrapolation to wider un-monitored regions.

4 RESULTS AND DISCUSSION

4.1 Empangeni Site

Figure 1 illustrates some of the data obtained from the automatic weather station at the OSCA site. The diurnal trend of temperature and relative humidity is typical, and the influence of rainfall on the aforementioned variables is evident. The drop in daily minimum temperatures and humidity, reflecting the colder, drier conditions associated with the approach of winter, are also in evidence.

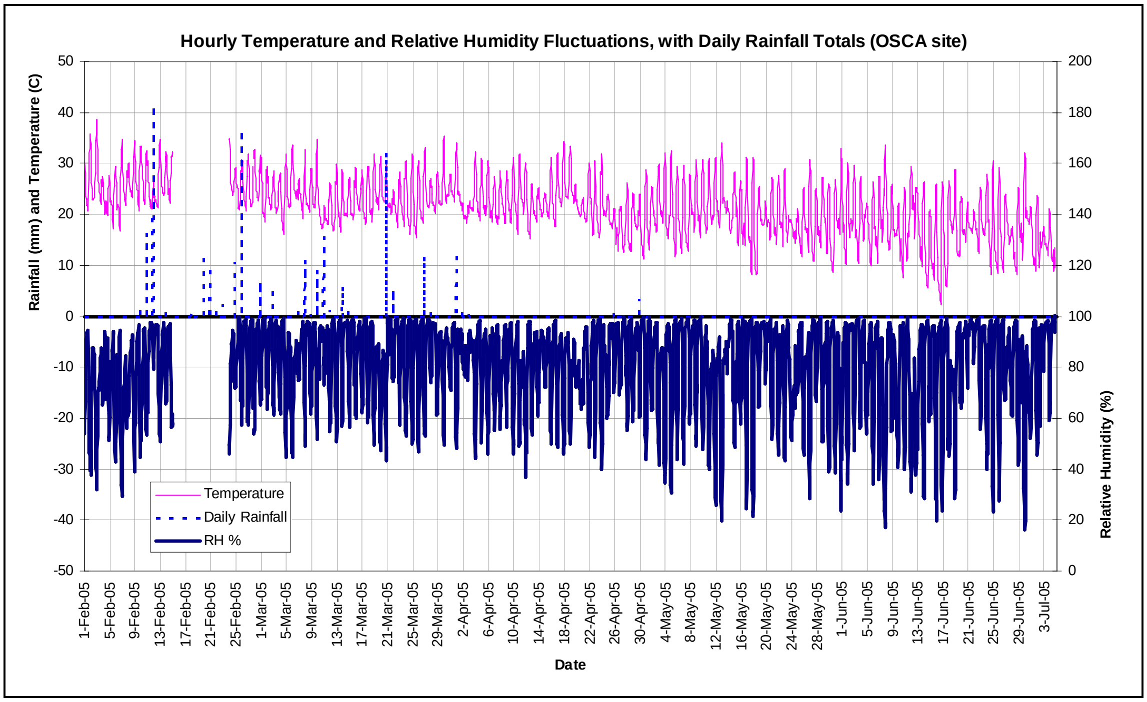

Figure 1: Hourly Temperature (ºC) and Relative Humidity (%) data collected by the automatic weather station at the OSCA site, near Empangeni.

Figure 2 illustrates raw sap flow data collected from a single probe set within a 3-year old *J. curcas* tree at the OSCA site.

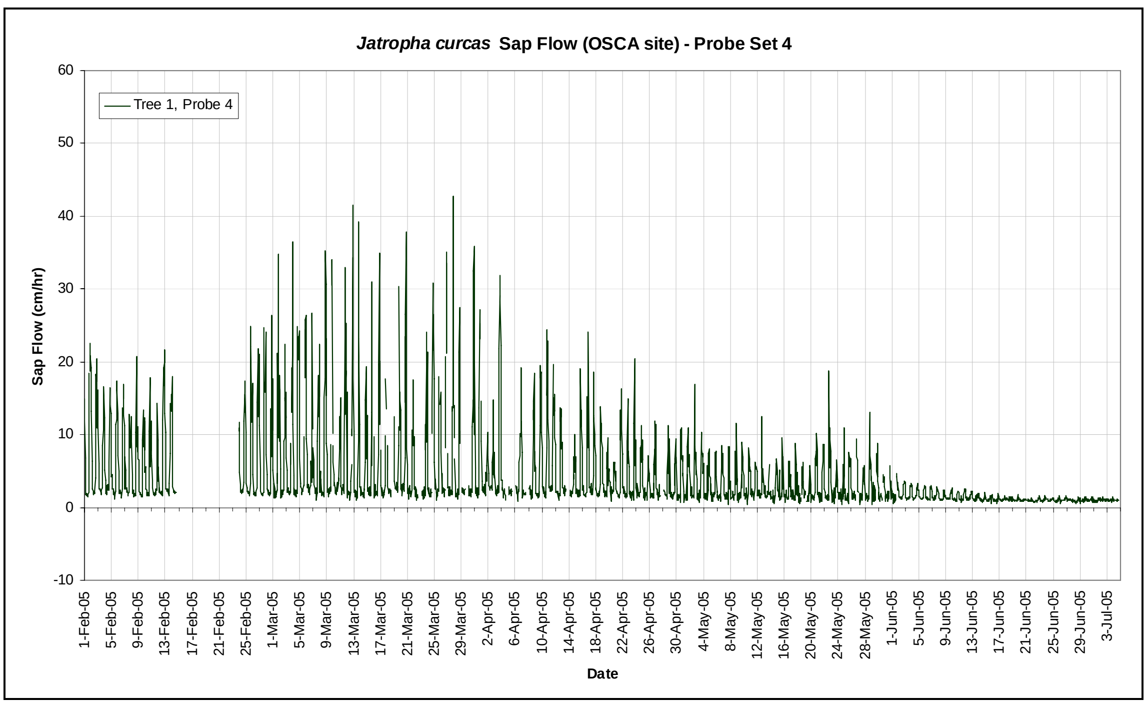

Figure 2: Hourly sap flow data (cm/hr) collected from probe set 4 (tree 1, probe 4) at the OSCA site, near Empangeni.

It is evident in Figure 2 that there is a clear diurnal trend to the data. This is consistent between all the probe sets. The peak transpiration rates vary but the gradual reduction in transpiration across all probes (as winter is approached) is noticeable. This diurnal trend is illustrated more clearly in Figure 3, which shows a typical daily trend of sap flow, temperature and relative humidity (RH), measured on 22nd March 2005 at the OSCA site.

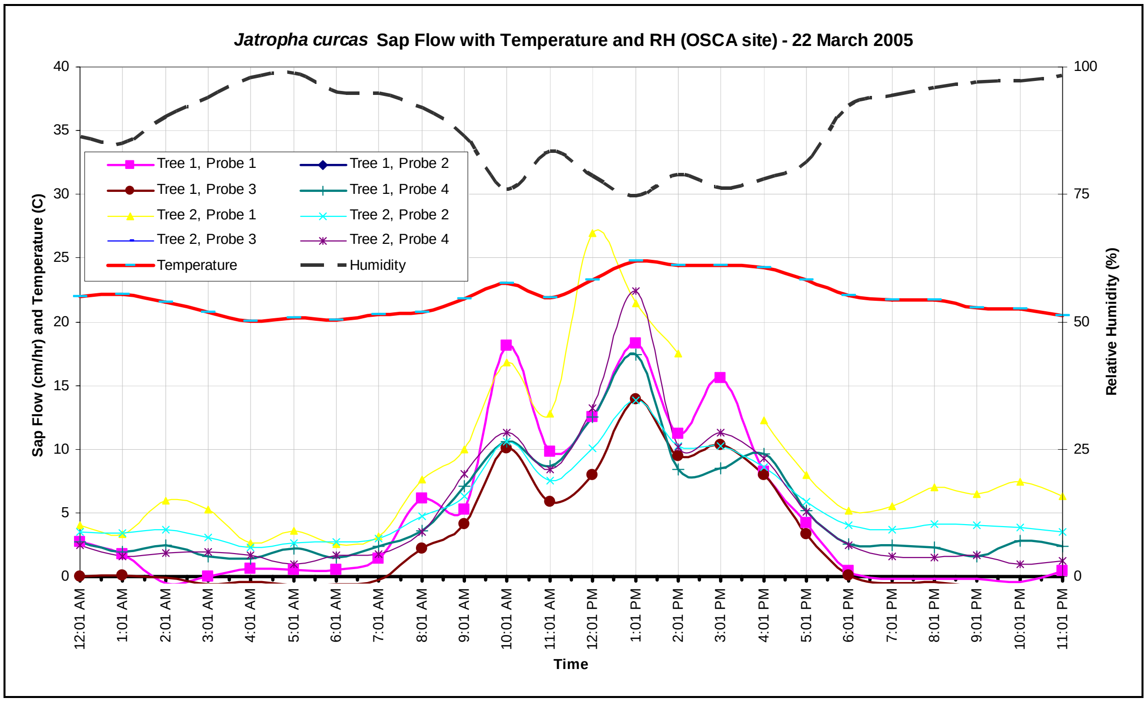

Figure 3: Hourly sap flow (cm/hr), temperature (°C) and relative humidity (%) data from the 22nd March 2005 at OSCA.

In Figure 3, the increase in sap flow associated with the onset of daytime transpiration (linked to increasing temperatures and solar radiation and decreasing relative humidity) is evident in all the probe sets from approximately 07h00 onwards. Thereafter the individual probe sets show good correlations between sap flow and vapour pressure deficit (i.e. a combination of temperature and humidity). For example, when there are brief drops in temperature (and increases in humidity) at 11h00 and 14h00 respectively, there are corresponding reductions in sap flow. There are also excellent correlations between sap flow and solar radiation (Figure 4).

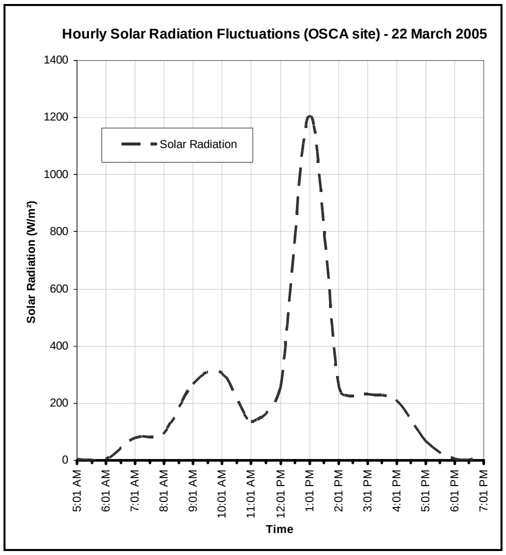

Figure 4: Hourly solar radiation data (W/m²) from the 22nd March 2005 at OSCA.

In Figure 3 the sap flow rates decline noticeably after 15h00 until transpiration ceases at night (18h00). In later months (May / June) sap flow begins later and ends earlier (08h00 to 17h00) compared to the summer period illustrated here. This is obviously associated with daylight length. The decreased peaks in sap flow towards winter reflect increasing water stress.

The third major component of the monitoring instrumentation at the OSCA site consists of the soil water content and soil matric potential sensors. Figure 5 shows the volume water content of the soil beneath the trees and the grass at three depths namely 0.15, 0.40 and 1.20 m.

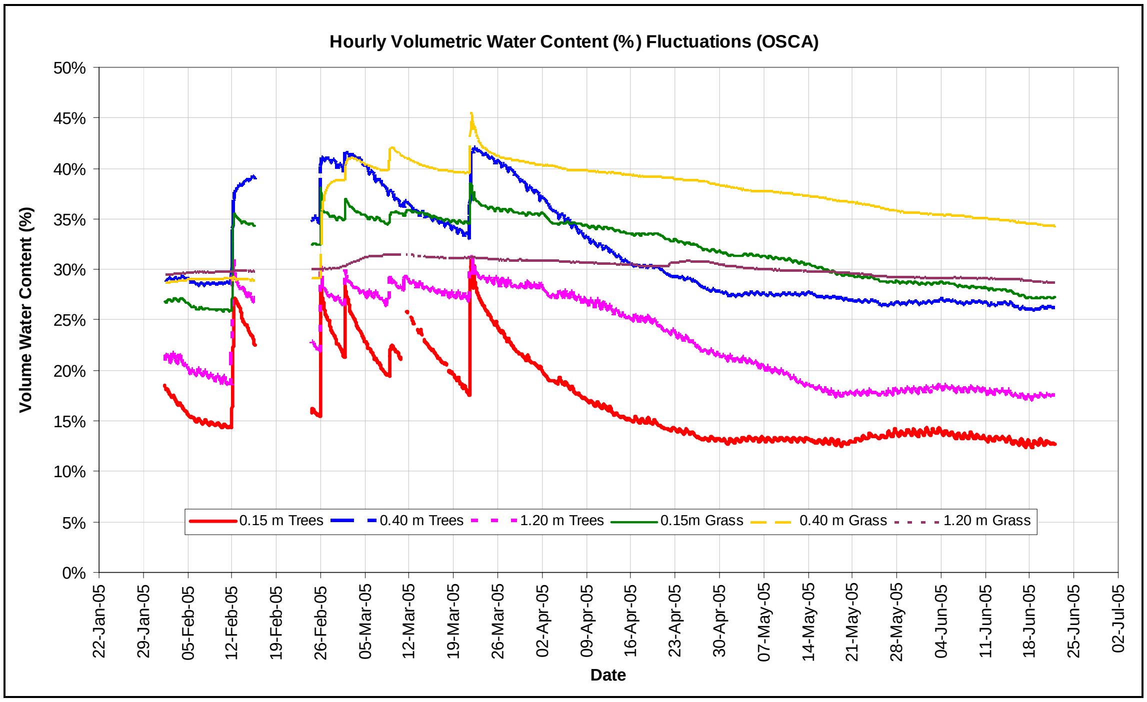

Figure 5: Water content (%) at selected soil depths beneath grassland and *Jatropha curcas* trees at the OSCA site.

Figure 6 is matric potential data from the OSCA site for the same period as above.

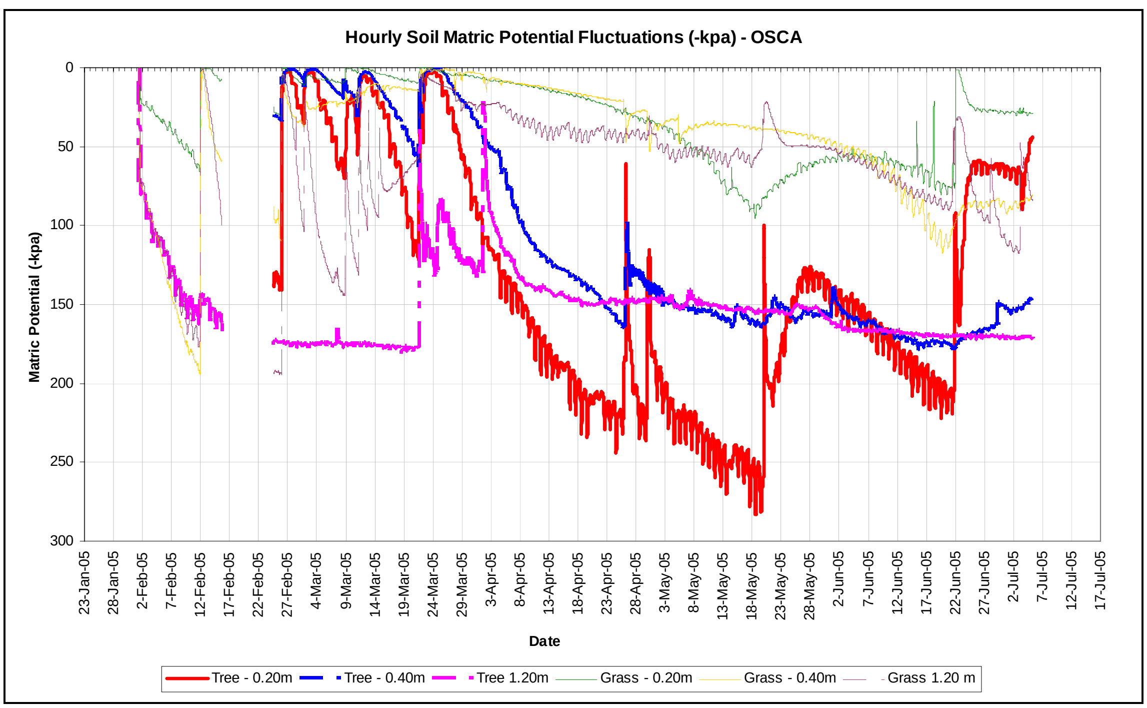

Figure 6: Matric potential at various soil depths beneath grass (thin lines) and *J. curcas* trees (thick lines) at OSCA.

During the month of March 2005 good rains fell at the OSCA site, which had a bearing on both the soil water content and water potential (these two parameters are inter-related). During this time the matric potential measured by all of the sensors rarely went below 100 kpa indicating fairly wet soil conditions and a period where plant stress due to water would be at a minimum. A brief dry period (no rain) occurred between the 13th to the 19th of March during which the matric potentials decreased, but this was abated by an intense rainfall event on the 20th (32.3 mm) which caused a rapid increase in matric potential to within the 0 to 25 kpa range. This was in essence the last major summer rainfall event for this region. Since then the soil's matric potential has been decreasing steadily as winter progressed.

The soil beneath the trees (thick lines) has dried out at a much faster rate than that below the grassland (thin lines), suggesting a comparatively higher consumption by the trees. The 0.2 and 0.4 m deep soils in particular showed the highest rate of decrease in matric potential which arises from a combination of direct uptake of water by the tree roots and from atmospheric evaporative demands. The decrease in matric potential for the deeper layers has been somewhat slower due to receipt of water from higher up the soil profile. Initially there was a rapid decrease in matric potential for the 1.2m deep soil but since early April this has remained fairly constant at about 160 kpa. Interestingly, the grassland site has maintained a relatively high matric potential (>50 kpa) during the early winter which is supported by corresponding high water contents (> 0.30 m^3 m^{-3}). A potential explanation for this is that at this time of year, unlike trees, the grass would be in a state of dormancy or reduced growth and therefore evaporation rates would be less accounting for wetter soil conditions.

4.2 Makhathini Site

Figure 7 illustrates raw sap flow data collected from a single probe set within an 11-year old *J. curcas* tree at the Makhathini site.

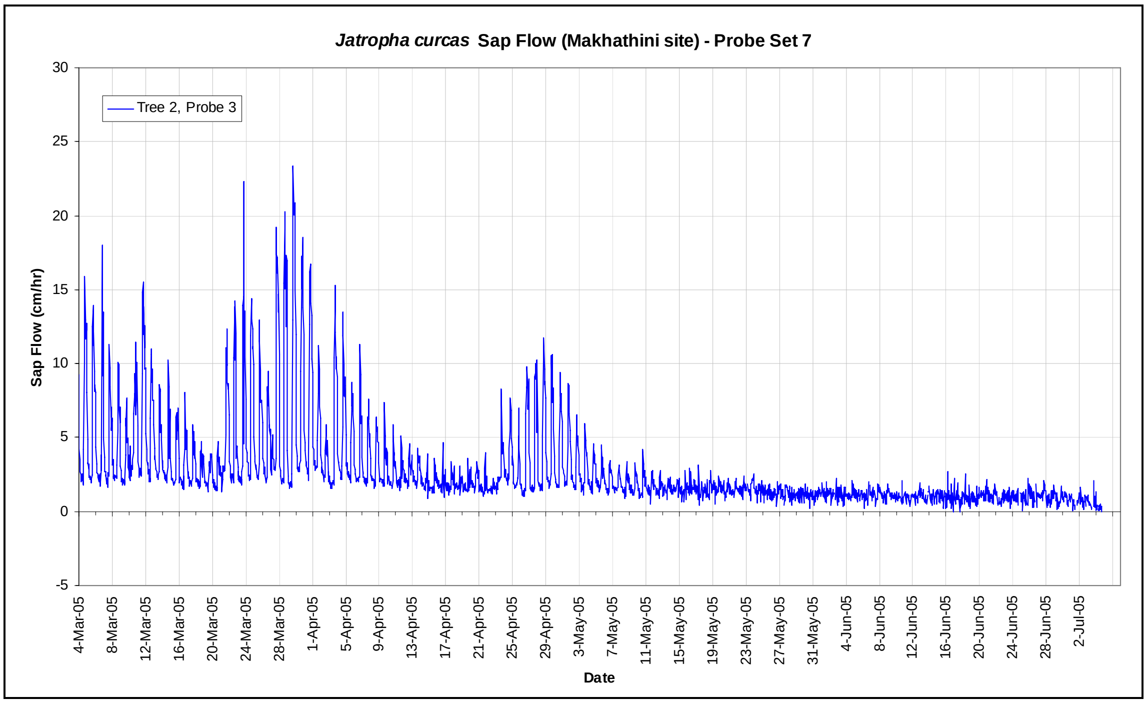

Figure 7: Hourly sap flow data (cm/hr) collected from probe set 7 (tree 2, probe 3) at the Makhathini site.

The sap flow data for the Makhathini site (Figure 7) shows a similar diurnal pattern to that of the OSCA site. The termination of sap flow at the approach of the dry winter months is also clear. However, there are some noticeable differences between the OSCA and Makhathini data. Firstly, the Makhathini sap flow data decline far more dramatically and significantly earlier in the winter season. While the 3-year old trees at OSCA continue transpiring until the end of May, the older Makhathini trees show no signs of sap flow after the 10th of May. In fact the data in Figure 7 already indicate a period of water stress in the second half of April (decreasing sap flow), which was only temporarily alleviated towards the end of April / early May. Temperature and humidity data suggest the renewed sap flow during this period was linked to increased water availability (from rainfall). It would appear therefore, that sap flow in the Makhathini trees is strongly influenced by fluctuations in water availability, while the OSCA trees appear to be limited only by season (deciduous, dryer and cooler winter conditions). For these reasons, and possibly tree-age differences as well, the OSCA trees have noticeably higher sap flow rates. However, in terms of volumetric water use these would be off-set by the greater cross-sectional area of the older and larger Makhathini trees.

Figure 8 shows a typical daily trend of sap flow, temperature and relative humidity (RH), measured between the 1st and 4th April 2005 at the Makhathini site. Again, the influence of cooler, more humid conditions in suppressing sap flow is evident.

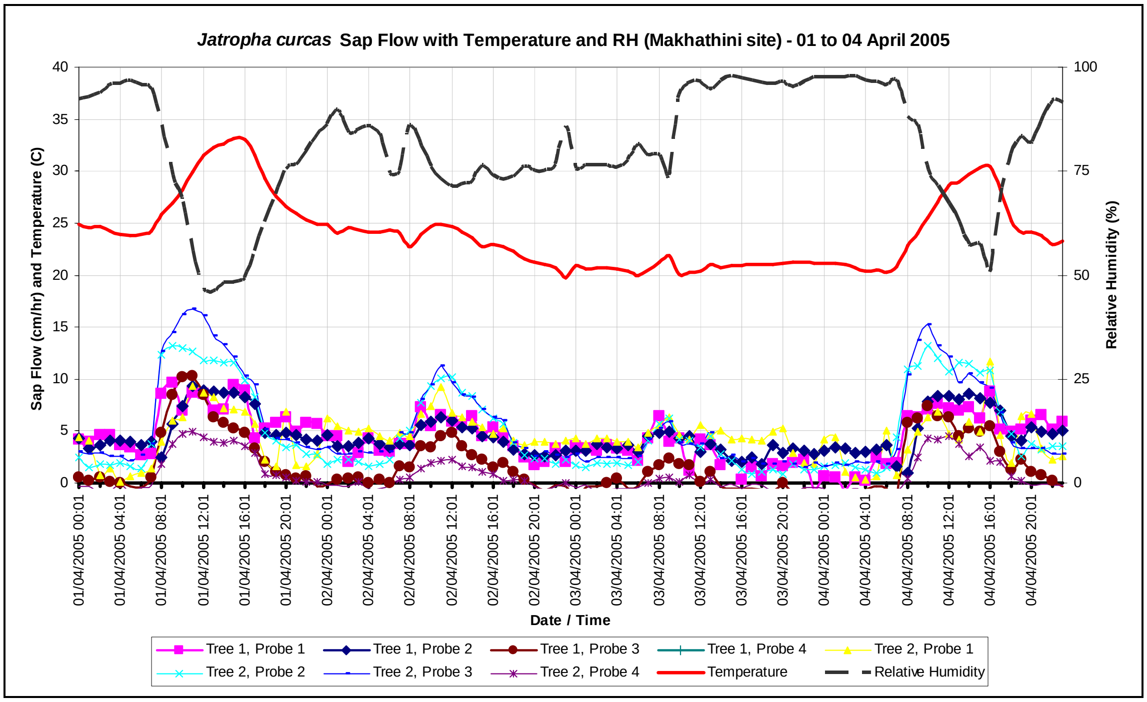

Figure 8: Hourly sap flow (cm/hr), temperature (°C) and relative humidity (%) data between the 1st and 4th April 2005 at Makhathini.

5 CONCLUSIONS

The instruments installed at the Owen Sithole College of Agriculture (OSCA) and Makhathini sites have so far proven to be reliable, and have produced good data. Although it is still early in the project, the study has begun to yield some interesting results. Early indications from the soil sensors are that the *Jatropha curcas* trees at the OSCA site are using more water than the nearby grassland. The variation in observed sap flow rates appears to be linked to tree size, mean daily vapour pressure deficit (VPD), and the temporal and spatial patterns of soil water deficits. There are clear diurnal patterns to the sap-flow, with no transpiration occurring at night, although the potential for hydraulic lift needs to be investigated further. The trees, which are deciduous, also seem to effectively 'shut down' during dry periods and in winter, when they lose their leaves. Peak transpiration rates occur during the warm wet summer months. The second monitoring site (Makhathini), being in a different area and of a different tree age, is contributing significantly to gaining a more balanced perspective to the water use patterns associated with this species. Sap flow rates in the trees at this site appear to be lower than those at the OSCA site, and respond far more dramatically to changes in water availability.

Regarding future work, it is envisaged that after continuous monitoring for 18 months, two modelling exercises will be conducted. These will consist of detailed modelling for the OSCA site, and a courser water balance modelling exercise for the purposes of extrapolation to wider regions, for which the data requirements of (i) meteorological data; (ii) soil parameters; and (iii) vegetation parameters will be accounted for from the field measurements described in this paper. The terms of reference for the project required that a site be extensively instrumented, monitored and modelled using appropriate software, to lend credibility to a subsequent modelling extrapolation exercise to wider areas having cultivation potential. It is acknowledged that the two isolated sites (with two representative tree ages) could by no means adequately represent all the potential growing conditions possible for this species in South Africa. However, this shortcoming will be addressed as far as possible through the modelling exercise.

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REFERENCES

Becker, K. and Makkar, H.P.S. 2000. Jatropha and Moringa. Available from < http://www.uni-hohenheim.de/~www480/docs/se990720/jatropha.htm > [Last Update Used: May 11, 2000].

Begg, J. and Gaskin, T. 1994. *Jatropha curcas* L. Available from < http://www.inchem.org/documents/pims/plant/jcurc.htm > [Last Update Used: June, 1994].

Burgess, S.O., Adams, M.A., Turner, N.C., Beverly, C.R, Ong, C.K., Khan, A.A.H. and Bleby, T.M., 2001. An improved heat pulse method to measure low and reverse rates of sap flow in woody plants. *Tree Physiology*, 21: 589-598.

Duke, J.A. 1983. Handbook of energy crops. Available from: < http://www.hort.purdue.edu/newcrop/duke_energy/Jatropha_curcas.html > [Last Update Used: January 7, 1998].

Gubitz, G.M., 1997. Biofuels and industrial products from *Jatropha curcas*. Proceedings from a Symposium held in Managua, Nicaragua. Graz, Austria: Technical University of Graz.

Henning, R. 1996. Combating Desertification: The Jatropha Project of Mali, West Africa. In: The Arid Lands Newsletter, 40 (Fall/Winter 1996). Available from < http://ag.arizona.edu/OALS/ALN/aln40/jatropha.html > [Last Update Used: November, 1996].

JANUS, 2004. JANUS Foundation – A small report on *Jatropha curcas*. Available from < http://www.janusfoundation.org/jatropha.htm > [Last Update Used: April 19, 2004].

Joubert, P.H., Brown, J.M. and Hay, I.T. 1984. Acute poisoning with *Jatropha curcas* (purging nut tree) in children. *South Africa Medicinal Journal*, 65(18):729-30.

Little, E.L., Jr., Woodbury, R.O., and Wadsworth, F.H. 1974. Trees of Puerto Rico and the Virgin Islands, vol. 2. Ag. Handbook 449. USDA, Washington, DC.

Mampane, K.J., Joubert, P.H. and Hay, I.T. 1987. *Jatropha curcas*: use as a traditional Tswana medicine and its roles as a cause of acute poisoning. *Phytother Res.* 11:50-1.

Morton, J.F. 1977. Major medicinal plants. C.C. Thomas, Springfield, IL.

NWA. 1998. National Water Act, RSA Government Gazette No. 36 of 1998: 26 August 1998, No. 19182. Cape Town, South Africa.

PIER, 2004. Pacific Island Ecosystems at Risk (PIER). Available from < http://www.hear.org/pier/species/jatropha_curcas.htm > [Last Update Used: January 1, 2004].

Pratt, J.H., Henry, E.M.T. Mbeza, H.F., Mlaka, E. and Satali, L.B. 2002. Malawi Agroforestry Extension Project: Marketing & Enterprise Program Main Report. Publication No. 47. USAID Contract.